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THE SHOT-HOLE DISEASE OF STONE-FRUIT TREES

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INTRODUCTION

Growers of stone fruits in California are well aware of peach blight or shot hole, caused by the fungus *Coryneum beijerinckii* Oud. [*Clasterosporium carpophilum* (Lév.) Ader.]. So important is this disease in peaches and apricots that a yearly spraying to control it has long been standard orchard practice.

The control of shot-hole disease in almonds has received less attention from the growers, probably because it occurs somewhat more sporadically in this crop than in peaches and apricots. When it does become serious in almonds, control attempts follow along the lines established for peaches, with apparently unsatisfactory results. One object of the work reported herein, therefore, was to determine whether an economical and effective spray program could be developed for almonds.

After a severe outbreak in peaches during 1935 a question arose as to the effect of delaying the spray until early winter, as seems to be the practice of some growers. A related problem was the efficiency of various new spray materials.

Since both foreign and domestic literature contains valuable data, this paper will summarize as much of this information as deals with our local problems and, in addition, will discuss the results obtained in the present work.

HISTORY OF THE DISEASE

The disease, variously known as peach blight, shot hole, *Coryneum* blight, fruit spot, winter blight, and pustular spot, is important in sections of North America, Europe, Africa, Australia, and New Zealand. First described in 1843 as attacking peaches near Paris, France,[(20)][3] it was reported from England[(6)] in 1864, and later from many other European countries.

Between 1882 and 1889 it occurred with such severity throughout northern New Zealand that a local variety of peach, the Maori, was practically exterminated.[(7, 10)] At about the same time it was reported from Australia.[(9)]

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[3] Superscript numbers in parentheses refer to "Literature Cited" at the end of the paper.

In 1904 it was widespread throughout Tunis and Algeria, Africa.[28]

In the United States, apparently, the disease was first reported in 1894 from Michigan,[27] where it attacked the peach. In 1894 it was reported

Fig. 1.—Typical circular lesions of the shot-hole disease on twigs, fruit, and leaves of peach. (From Ext. Cir. 98.)

from western New York[5] on the apricot and from Ohio[24] on the peach. A few years later it was reported on both the peach and the apricot throughout most of New York.[26] This report, resulting from a survey of

fruit diseases in New York, contains a fairly concise description of the disease and drawings of the spores of the fungus.

On the Pacific Coast shot hole was first reported in 1900.[22] During the next ten years it became destructive to peaches in California [25] and

Fig. 2.—Shot-hole disease. *A,* Showing a peach twig defoliated by the disease during the spring of 1936; *B,* a peach twig killed by the disease during the winter of 1935–36.

Oregon.[8] At present it is known in fourteen states: Washington,[17] Oregon,[4, 8, 18] California,[11, 25] Colorado,[19] Utah, Idaho, Mississippi, Indiana, Ohio, New Jersey, Massachusetts,[3] Michigan,[12, 27] New York,[5, 26] and Kentucky.[29] It is of greatest economic importance in the three Pacific Coast states and in Utah and Idaho.

SYMPTOMS

The disease manifests itself somewhat differently on peach, almond, and apricot. In peach, lesions occur abundantly on twigs and cause severe blighting, whereas in apricot they seldom occur on twigs. Almond twigs,

although attacked somewhat, are not usually blighted. The blighting of dormant buds, though common in all three hosts, is most abundant in apricot, where it causes much loss. Foliage infection and the resulting defoliation may be equally severe with all three hosts. Fruit infection is usually not severe in the varieties of peaches grown in this state but is severe in the apricot and the almond. Blossom infection was found fre-

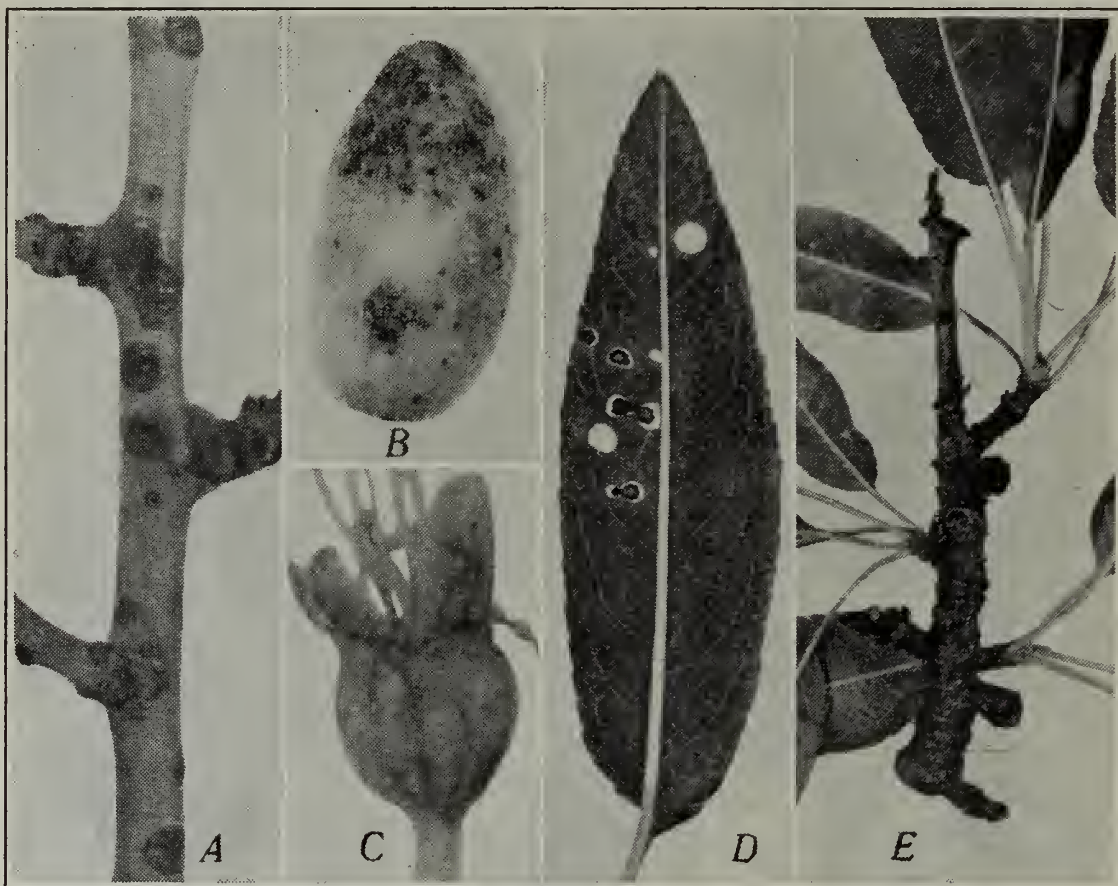

Fig. 3.—Shot-hole disease of almond. *A*, Typical circular, craterlike lesions on a twig; *B*, concentration of lesions at blossom end of fruit, the spores for infection having come from an infected blossom husk that adhered to the blossom end of the fruit; *C*, lesions on sepal and calyx cup of blossom; *D*, shot-holing effect produced in leaves; *E*, spurs and end of terminal twig affected by the disease. The buds borne on these parts harbor the fungus from one season to the next.

quently in almond during this study; it occurred somewhat in the Gaume peach during 1936, but was not observed in apricot.

The symptoms on different parts of the hosts are described below.

Twig Infection.—The twigs produced during the preceding growing season are seats of infection. The first symptoms occur in winter or early spring as small, black spots scattered along the twigs. Later the spots increase in size; their centers become somewhat lighter in color, and sink. On peach twigs the lesions frequently continue to extend and may become ½ inch long or more (fig. 1). Longitudinal cracks develop in the periderm across these lesions, and copious gum exudation may occur. When numerous, the lesions girdle and blight the twigs (fig. 2, *B*).

On almond, twig lesions seldom become more than 4–5 millimeters in diameter; are well-defined, circular, craterlike pustules; and are frequently delimited at the periphery by a cracking of the periderm (fig. 3, *A*). Figure 4 gives an enlarged view of twig lesions. For some reason almond twigs are not killed extensively by the disease. In a few cases, as in figure 3, *E*, a short portion of terminal or a spur is blighted. Lesions are rarely found on apricot twigs; and, in consequence, these twigs are seldom killed by the disease even though most of the buds are affected.

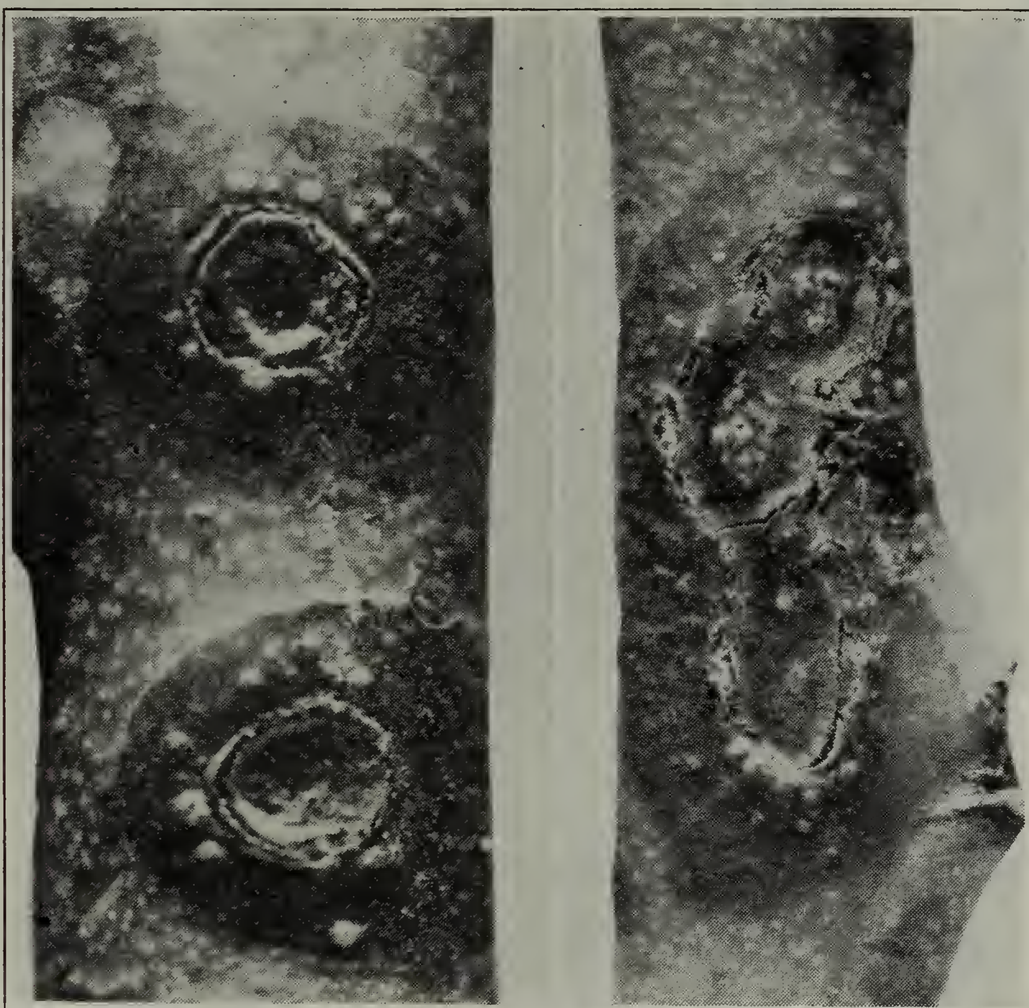

Fig. 4.—Enlarged views of lesions of the shot-hole disease on almond twigs.

Leaf Infection.—The leaf lesions appear first as small, purplish spots with yellowish centers. As they increase in size the tissues at the center turn brown; the periphery becomes separated from the healthy tissue; and the infected area drops away, producing the well-known shot-hole effect (fig. 3, *D*). On young leaves the diseased area may increase in size rapidly and kill a large portion of the leaf blade. Heavy defoliation frequently follows severe leaf infection, resulting in weakened trees.

In peach orchards during the spring of 1936 the fungus invaded the base of leaf stems, causing the leaves to wither. This symptom may be

mistaken for brown rot, which blights twigs and leaves of peach, apricot, and almond.

Fruit Infection.—Lesions on fruit resemble those on leaves in being at first small, purplish spots (figs. 1; 3, *B*; 5, *C*). Later the center of the lesion turns brown or black, and sinks. On young growing fruit, particularly apricot, the diseased areas are cut off from the underlying healthy

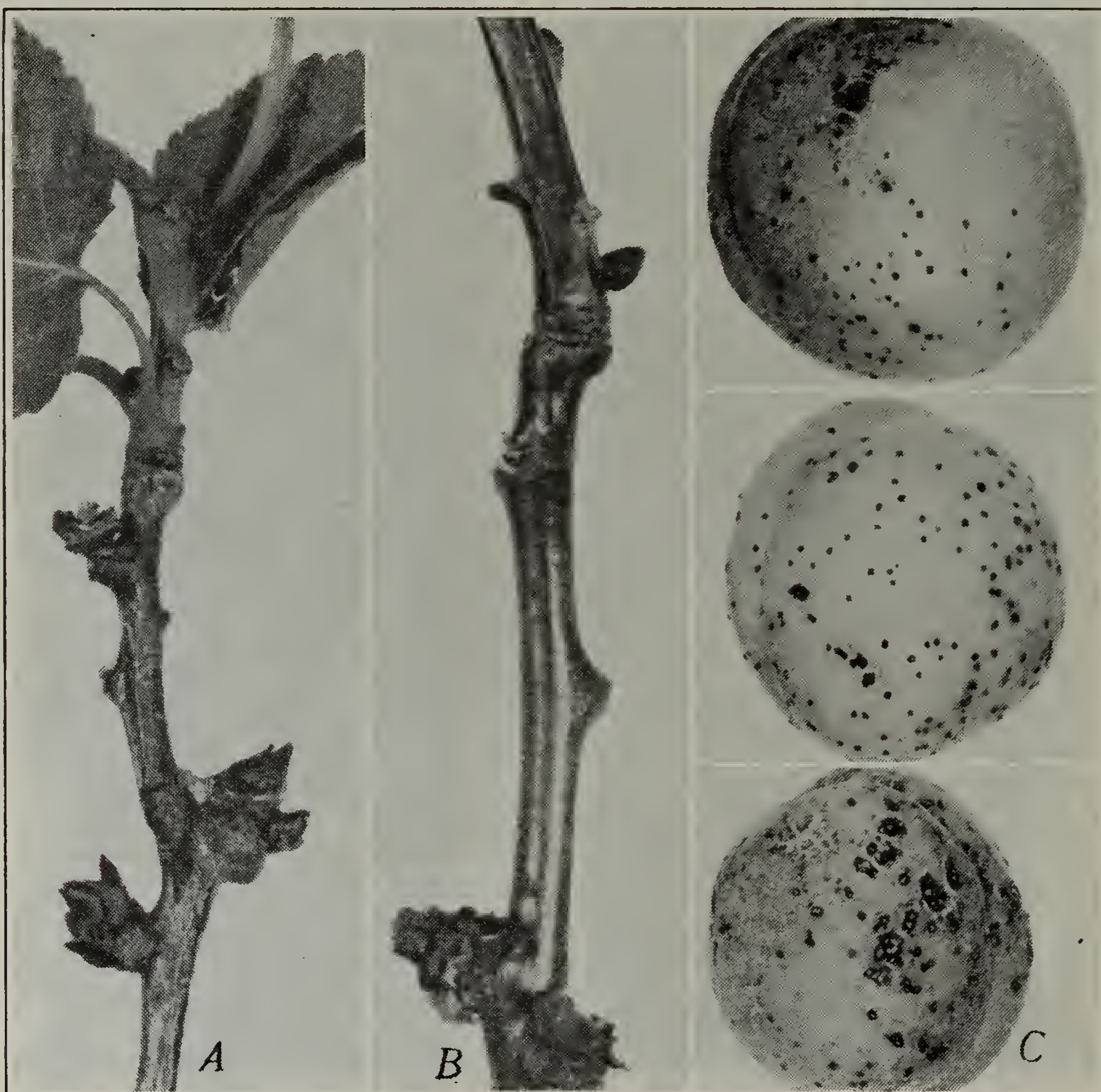

Fig. 5.—Shot hole on apricot. *A, B,* Blighted blossom buds, jet black and exuding gum; *C,* infected fruit. The spots coalesce to form unsightly scabby areas, which render the fruit unsalable.

tissue by a corky layer and become, in consequence, raised, dry, scurfy disfigurations (fig. 5, *C*).

The development of numerous lesions along the suture of almond fruits results in the cracking of the pericarp and the drying out of the embryo. Almond fruits are more prone to produce gum at the point of infection than is either peach or apricot.

Dormant-Bud Infection.—The apricot is particularly susceptible to infection through the dormant buds (fig. 5, *A, B*). Diseased apricot buds

turn black and, frequently, as gum is exuded over and around the scales, they assume a polished appearance. They remain attached to the twig and are not easily dislodged. The fungus in the affected bud does not usually extend into the twig.

On the peach, aside from the buds killed when the twigs are blighted (fig. 2, *B*), numerous buds are either attacked directly or invaded by the

Fig. 6.—The shot-hole disease on blossom buds and blossoms of Ne Plus Ultra almond. *A*, Blossom buds blighted in different stages of development; *B*, two blighted blossom buds and one healthy blossom. Diseasd buds supply spores for infection of surrounding leaves and fruit. *C*, Lesion of *Coryneum* expanding to involve a large portion of the calyx cup. Such a blossom will probably not be blighted, but the diseased calyx cup will furnish spores to infect the fruit as it develops.

fungus spreading from a lesion that develops on the twig adjacent to the base of the bud. In the latter case the diseased buds are noticeable because of the gum they exude. In certain cases buds located in the axils of leaves are blighted at the time leaves are infected.

Blighting of leaf buds has been less abundant with almonds than with peaches. Blighting of blossom buds is, however, fairly common. As shown in figure 6, *A,* blighting may occur at various stages in the development of the blossom bud, from a condition in which the bud scales begin to separate to one in which the blossom has entirely emerged. Although not always abundant enough to reduce the crop materially, blighted almond buds are nevertheless of importance, constituting an abundant spore source for leaf and fruit infection. This phase will be discussed in detail under a later heading.

Blossom Infection.—The almond blossom may be infected after it emerges from the bud. The lesions located either on the sepals or on the calyx cups at first resemble those on leaves and fruit (fig. 3, *C*), being small, circular, purplish areas with a tan center. Later the lesion rapidly increases in size, eventually involving much of the calyx cup (fig. 6, *C*). At times the lesion spreads to the blossom stem, causing the death of the entire blossom. More frequently, however, the fungus kills the blossom (or opening blossom bud) by invading the base of its stem. Apparently, as the bud scales separate, rain washes the spores to the base of the bud, where conditions favor germination and infection.

As mentioned earlier, blossoms of Gaume peaches in one orchard were attacked by the fungus in 1936. Aside from an earlier case of a flowering peach, this is the only extensive case of blossom infection found outside of the almond. None has been observed in the apricot.

STONE FRUITS ATTACKED BY THE DISEASE

The following species of *Prunus* are susceptible to the disease:[1, 2] peach (*P. persica* Stokes); apricot (*P. armeniaca* L.); nectarine (*P. persica* var. *nectarina* Maxim.); almond (*P. amygdalus* Stokes); plum (*P. domestica* L.); cherry-laurel (*P. laurocerasus* L.); and several cherry species such as *P. avium* L.; *P. serotina* Ehrh.; *P. virginiana* L.; and *P. padus* L. In addition, the present writer has found it several times on *P. davidiana* Franch.

The disease varies in its destructiveness to these hosts in different parts of the world. It is serious on cherry, for example, in Switzerland,[13, 32] Germany,[1] and Washington;[17, 21] whereas it is usually inconsequential on this host in New Zealand[10] and California. The hosts consistently suffering economic loss in California are peach, nectarine, apricot, and almond.

THE FUNGUS CAUSING THE DISEASE

Description of the Fungus.—The cause of the shot-hole disease is a minute parasitic plant (fig. 7) that invades the tissues of the tree and

grows at their expense. It is composed of two essential parts: (1) the mycelium, a system of slender, thread-shaped structures that grow into the tissues of the host plant and absorb the necessary nutrients, and (2) the spores or conidia, 3 to 5-celled oval bodies produced on stalks (conidiophores) arising from the mycelium. The spores are easily detached from the conidiophores and are, in consequence, the means of spreading the fungus about the orchard. They germinate (fig. 7, *B*) upon being immersed in water, producing thin-walled germ tubes capable of pene-

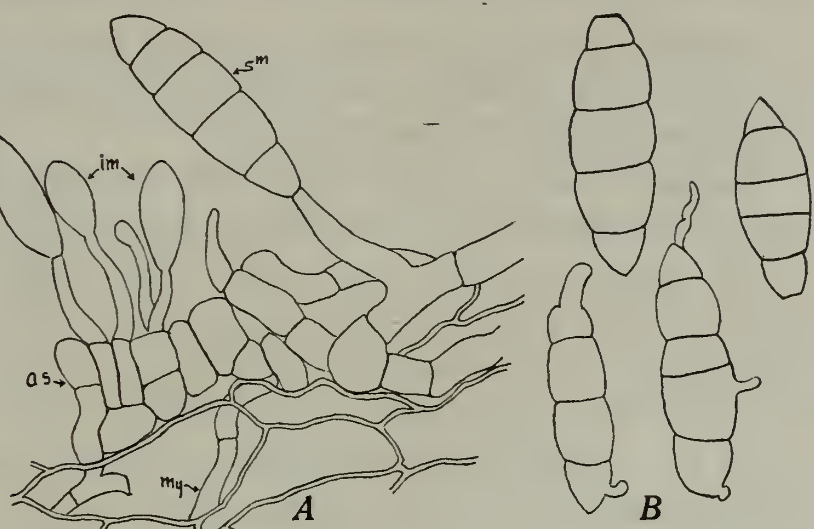

Fig. 7.—The shot-hole fungus, *Coryneum beijerinckii*. *A*, Method by which spores are produced on almond blossoms; *im*, immature spore; *m*, mature spore. Note the mass of fungal elements (*as*) from which the spores are produced and the mycelium (*my*) extending from this mass of cells into the tissues of the blossom. The mass of loosely packed mycelium (*as*), though extensive in some cases, is composed of only a few cells in others. *B*, Differently shaped mature spores, two of which are germinating.

trating the tissues of the tree. After entering the host the germ tube continues to grow and give rise to mycelium. According to one investigator[23] a small knot of mycelium (regarded by some as an ascervulus) develops and breaks through to the surface of the host tissue. The spores are then produced from this loosely packed knot of mycelium.

Holdover Sources of the Fungus.—In this state the fungus is required to survive several months during the summer, when conditions are unfavorable for its activity. One investigator[31] in France claims that the fungus produces in the diseased leaves that fall to the ground a type of spore (ascospore) presumably capable of spreading about the orchard. Later observations, both in Germany[1] and in California,[25] failed to confirm this claim. During the present study several attempts to find such a type of spore also failed. In peaches the fungus survives from one season to the next in twig lesions and in blighted buds. In the apricot the holdover source is the blighted buds, lesions on twigs being rare. In the

almond there are several holdover sources, varying in abundance from orchard to orchard and from variety to variety. Lesions, though occurring on almond twigs to some extent in the experimental orchards, were not sufficiently abundant to constitute the major holdover sources. Infected dormant buds, particularly blossom buds, on the other hand, were sufficiently numerous to account for much of the holdover in almonds. In two orchards, at least, diseased blossoms were also found to harbor the fungus during the summer.[33] In one experimental orchard almond blossoms blighted by the brown rot fungus and remaining in the tree over the summer were found, in many cases, to harbor the shot-hole fungus also. Apparently the shot-hole fungus had attacked these blossoms before they were blighted by brown rot.

For each almond blossom actually killed by the shot-hole fungus, numerous others are attacked but not blighted. In such cases the disease is present on the sepals or calyx cups (husks). The husks are usually shed soon after the fruit sets and starts to grow (fig. 3, *C*). Sometimes, instead of dropping, the husks adhere to the upper end of fruit for a considerable period after separating from the base. Under such conditions the fungus is in a particularly favorable position to infect the fruit as well as the surrounding leaves. Spores are produced on infected husks much more abundantly than on twig lesions. When rains occur, these spores are washed downward over the fruit and leaves. The fruits, in consequence, often develop numerous lesions near the blossom end (fig. 3, B).

The blighted buds remaining in the tree are, in the apricot and the almond, particularly important sources from which the fungus spreads by means of spores to the leaves and fruit when these appear. In spring one can often locate blighted buds by the presence of numerous lesions on leaves beneath such buds. In the section dealing with control the amount of leaf infection in peaches will be shown to follow closely the amount of twig infection. Leaf infection in almond, on the other hand, corresponds in amount more closely to bud infection than to twig infection.

Longevity of the Fungus in Twig Cankers and Diseased Buds.—The fungus survives in the diseased parts of the tree both as mycelium and as spores. One investigator[23] several years ago found that spores kept dry remained alive for at least 15 months. In the present work, diseased peach buds taken from the twigs in early spring and kept out of doors in a dry condition contained viable spores when examined in the autumn.

Frequent observations indicated that viable spores are present in blighted buds at all times of the year. The fungus remained alive in peach twigs from the winter in which the lesions were formed to a year

from the following summer; and when given proper temperature and moisture conditions, it produced numerous spores of high germinability. Lesions, in consequence, formed during one winter or spring furnished spores not only for twig infection the following winter, but also for leaf infection the next spring thereafter. This ability of the fungus to remain alive in blighted buds for more than a year has an important bearing on any control program having as its primary object the prevention of twig infection, as will be shown later when the spraying experiments are discussed.

The prolific production of spores in blighted peach buds was shown by the following experiment: Twigs bearing diseased buds were washed in a stream of water. At first the water contained numerous spores; but as the washing continued, all the spores were apparently washed away. The twigs were then placed in a moist chamber kept at 72° F. At intervals of 6 hours the twigs were again washed, and the drip water was examined for spores. The results indicate that within 6 hours, in some cases, abundant new spores were formed. As many as three crops of spores were apparently produced within 72 hours.

Dissemination of Spores.—Rain is probably the most important single factor spreading the spores throughout the trees. In addition, possibly, spores in small particles of water may be disseminated in a lateral direction for short distances, depending on the wind velocity. They are probably not spread about to any great extent during dry weather. In the first place, they are not easily disconnected from the conidiophores by dry air, as is shown by several experiments where a jet of air was directed over peach-twig lesions held close to glass slides. Only an occasional spore was caught in this manner. If, however, a drop of water was allowed to fall upon the lesions and was then collected on a glass slide, numerous spores were found. Spores borne between the scales of blighted buds were not dislodged by air currents, but when the bud was wetted by a drop of water they were dislodged in great numbers.

Upon being placed in a drop of water on glass slides the spores settled rapidly, and if kept wet for 45 minutes or more they remained attached to the glass even though a comparatively strong stream of water was directed over them. This observation agrees with earlier studies[23] showing that from the beginning of germination, which is within 1 hour after being wetted, the spores become attached to the substratum by a mucilaginous sheath surrounding the germ tube; and thereafter they are not easily washed away by water.

Apparently, therefore, the spores are well adapted to dissemination by rain; and upon being in contact for a short while with the surface of susceptible tissue, they are not easily dislodged.

DEVELOPMENT OF THE DISEASE

As mentioned earlier, the fungus is carried over the unfavorable periods of summer as mycelium and spores in diseased twigs and buds. As soon as autumn rains begin, conditions again favor its dissemination and development. With its renewed activity, infection of the twigs can be expected provided other conditions are favorable. The discussion in this section deals with the time of disease development and with the circumstances influencing it, as far as known.

Mode of Infection.—Though no information is available as to the method by which the hyphae of the germinating spore enter twigs, they are known to penetrate directly the unbroken epidermis of leaves.[23] One investigator[21] claims that infection also occurs through stomata of leaves.

Incubation Period.—The time elapsing between the entry of the fungus into the tissues of the tree and the appearance of the first disease symptoms has not been studied carefully. One worker in Germany[1] records incubation periods averaging 6–8 days for the disease on leaves and fruit and 7–11 days on twigs. During the present work two experiments with leaves indicate that at 72° F leaf lesions may appear 5 days after infection. Lower temperatures would undoubtedly lengthen the incubation period.

Later in this section the relation of rains to twig infection of the peach during the winter of 1935–36 will be discussed. By observation of marked twigs during the autumn and winter, the time at which the major waves of disease appeared was determined. Although the exact length of the incubation period could not be determined from these data, information of considerable practical value was secured. The first major wave of disease, for example, was found to be initiated during the long rain period beginning on December 26. The disease appeared about 14 days after this date. The incubation period was therefore somewhat under 14 days, since the fungus was probably not established in the twigs during the first day or so of rain.

Development of the Disease in Relation to Climatic Conditions.—The year-to-year rise and fall in the severity of this disease is governed in no small degree by climatic conditions. Particularly is this statement true of rainfall. The total amount of rainfall, however, is secondary in importance to the length of the individual rainy periods. Since a certain amount of time is required for the spore of the fungus to germinate and to infect the host, and since the spore requires moisture for these processes as well as for dispersal, the surface of the host parts must be wet for a considerable period. The spores, as mentioned earlier, are so produced

that they are adapted to being spread about by the rain. Rain, therefore, acts in a twofold capacity: (1) aiding in the liberation and distribution of the spores and (2) permitting the spores to germinate and to infect the host.

The length of the rainy period necessary for germination of the spore and infection of the host has not been adequately investigated. It would, in all probability, be influenced by temperature. In two experiments

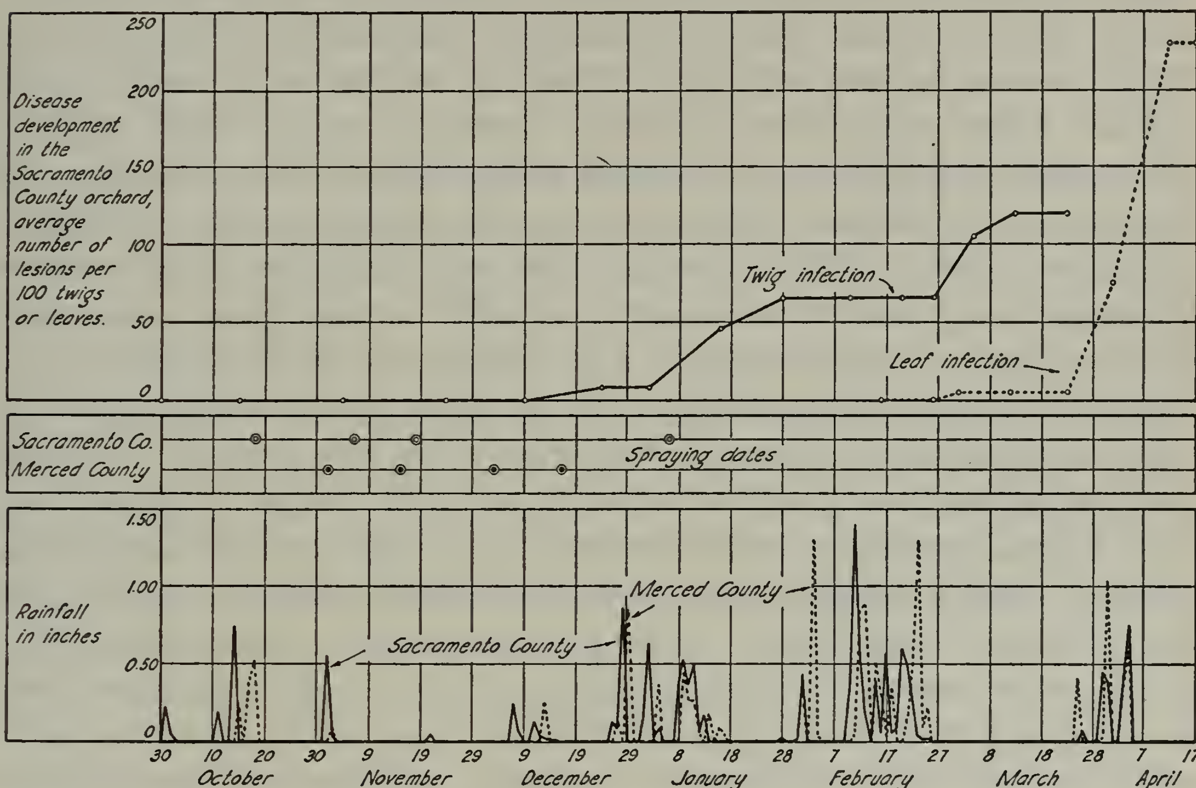

Fig. 8.—Relation of rainfall to development of the shot-hole disease on peach twigs and leaves and to the dates of spray applications at the Sacramento County and Merced County peach orchards.

current-year shoots of the peach, bearing eight to ten leaves, were cut from the tree during the spring of 1936. The leaves were sprayed with a water suspension of spores of the fungus. The twigs were placed with their cut ends in beakers of water, and all were inclosed in a moist chamber at 72° F. At 3-hour intervals twigs were removed and placed in beakers of water kept under room conditions. Lesions developed within 5 to 7 days. Judging from the results of two experiments, no infection occurred unless the leaves remained moist for 24 hours or more after the spores had been placed on them.

In field observations, moreover, twig infection in peaches was not found to occur during the first short rains of autumn. In the late summer of 1935, peach twigs produced during the same year were marked, and the number of lesions appearing on these twigs was noted at intervals throughout the autumn, winter, and spring. A few lesions appeared dur-

ing the last half of December (fig. 8); but not until January did the disease develop in abundance. From the end of January to the end of February no more disease appeared, but during the first half of March it again developed abundantly. By the end of March, in fact, the tagged twigs were so severely blighted that observations were discontinued. In examining the relation of these separate disease waves to rainfall we see that despite several fairly heavy rains during October and November, no disease resulted. Not till after the long rainy period beginning on December 26 did the disease develop abundantly. Similarly, not till after the 15-day rainy period, beginning February 10, did new disease again appear. These results show a relation between the length of the rain and the amount of infection: the autumn rains, being of short duration, did not initiate the disease, whereas the extended winter rains resulted in abundant infection. This information has practical value, for it explains why sprays applied in November, even after several short rains, gave good control of twig infection. Two reasons could heretofore be advanced to explain this situation: (1) As there were no viable spores in the tree at the end of the hot, dry summer, no infection could occur until new spores had been produced—that is, not till infected twigs and buds were wetted by the first autumn rains; (2) as suggested above, the first autumn rainy periods were too short to permit the spores to germinate and to infect twigs. Since, in the previous section, viable spores were shown to be present during all seasons of the year, the first explanation is not tenable. The second, however, seems to meet all the facts. In a later section, the control obtained by spraying at different times during October, November, and December, 1935, will be shown to follow closely the development of the disease as just outlined.

The peach-twig infection just discussed included that occurring in buds as well as on the internodal surfaces of the twigs; both types of infection occurred simultaneously, apparently requiring similar climatic conditions. In almond, on the other hand, the two types of infection did not always develop at the same time. Infection buds, for example, did not appear until the buds began to swell in the spring, whereas lesions on twigs first appeared during midwinter. This different situation is exhibited by the two stone-fruit species apparently because in the peach, bud blight is often caused by entry of the fungus into the twig at the base of the bud and later invasion of the bud itself, whereas in the almond the fungus apparently enters the bud between the scales. As mentioned in a former section, blighting of the almond blossom buds occurs from the time the scales begin to separate until the blossom is opened, a fact indicating that the scales protect the blossom parts to some extent.

Observations during three seasons show infection to occur in almond twigs at about the same time as in the peach. In 1935–36 roughly 80 per cent of the lesions were initiated during the long rainy period beginning on December 26, 1935; the remainder during the 15 days of rain beginning February 10, 1936. A spray applied in autumn before infection has occurred should therefore prevent almond-twig lesions; that this can be done will be shown later.

In years when rains occur in late spring, peach foliage may be attacked and drop from the tree. Since the young fruits depend for their growth on food materials manufactured by the leaves, they are arrested in their development and drop if the trees are heavily defoliated. The crop may also occasionally be reduced if the fungus attacks the blossoms; but this trouble is apparently less common in peaches than in almonds.

The disease on peach leaves was studied in 1936 by observing tagged leaves on unsprayed trees (fig. 8). A few lesions developed the first few days of March. These resulted from infection during the rainy period from February 10 to February 25 and would undoubtedly have been more abundant had more foliage been exposed. As it happened at the end of this rainy period, only an occasional leaf tip was projecting from between the scales of the more advanced buds. Leaf infection did, however, become abundant and cause considerable defoliation early in April. Obviously, then, the disease appeared after the series of rains that fell between March 26 and April 4. The fact that it did not develop during the dry weather of the second and third weeks of March but did develop after the rains of late March and early April shows how dependent it is on rainfall.

Leaf infection began to appear 6 days after the beginning of the rainy period and continued to appear until 8 days after the end. Although 6 to 8 days can in this case be only an approximation of the incubation period, it agrees very closely with the experimental results obtained in Germany,[1] as mentioned earlier in this section.

In three years of observation almond leaves were found to become infected as soon as they appeared in the spring. Since the number and the length of the rainy periods decrease as spring advances, the almond leaves, developing earlier in the spring than peach foliage, are exposed to more frequent and more prolonged rains, and, in consequence, are more liable to infection. This may be the reason why the almond is more commonly defoliated than the peach, since peach foliage seems highly susceptible when exposed to infection. Similarly, almond blossoms develop earlier in the spring than do those of the peach and are more commonly infected, probably because they are exposed to more frequent and more prolonged rains. Blossoms of the Gaume variety of peach in

one of the experimental orchards proved susceptible when, in 1936, they began to appear during rains in late February.

In three years, leaf lesions first appeared on almond approximately as follows: in 1934 on March 5; in 1935 on February 28; and in 1936 on March 3. Climatic conditions did not favor later development of the disease in 1934; but in 1935 and 1936, particularly in the former year, heavy defoliation occurred during March and April. After the rains that occurred between March 26 and April 4, 1936, for example, leaves became severely diseased and were constantly dropping from the trees during late April.

The development of the disease on almond fruit closely paralleled the disease on foliage, a fact indicating that conditions favorable to leaf infection also favor fruit infection.

So far nothing has been said concerning the effect of temperature on disease development. Though almost no information on this point is at hand, one may safely say that temperature fluctuations during the ordinary California winter and spring do not strictly limit disease development, as do fluctuations in rainfall. On the other hand, some temperatures are certainly more favorable to the disease than others: low temperatures prolong the period between infection and appearance of lesions; and higher temperatures, up to a certain point, shorten the period.

CONTROL

Control of the disease falls into two phases: (1) control of twig and dormant-bud infection and (2) control of leaf, fruit, and—in almonds—blossom infection. The comparative importance of these two phases of control, as far as economic loss is concerned, varies somewhat with the different species of stone fruit. Thus economic loss in the peach comes primarily from the destruction of fruiting twigs and the defoliation of the tree, fruit infection being, in most years, of secondary importance; economic loss in the apricot comes from destruction of fruit buds, reduction of crop through defoliation, and impairment of the marketing quality of the fruit by blemishing; economic loss in the almond comes from crop reduction through defoliation, blossom blight, and malformation of fruit.

Efforts in the past have been directed towards control of one or both of these phases. Probably the earliest experiments on control were conducted on peach in Ohio in 1898,[24] the purpose being to prevent fruit spotting by spraying after the fruit had set. Later observations and experiments in California,[25] with the purpose of preventing twig infection, resulted in the application of bordeaux mixture 30–35–200 between

November 1 and December 15, and again in the spring before the buds began to swell, the latter treatment being primarily for leaf-curl control. September was found to be too early, February too late, for efficient control. Later modifications consisted in omitting the spring application, since the autumn spray was found to prevent leaf curl effectively.

The value of an autumn application of fungicides for peach-blight control was further demonstrated in Oregon[8] during 1907 and 1908. The object in this case was to prevent the disease from attacking fruit and leaves, no mention being made of twig infection. By spraying with either bordeaux mixture 5–6–50 or liquid lime-sulfur 1–10 on November 1, on May 10 (after the fruit was set and had started to grow), and again on June 1, the disease on fruit and leaves was sharply reduced. The November application was found to be the most important of the three. Preblossom sprays, on the other hand, had little value in preventing fruit and leaf spotting by this fungus.

Because the single-spray program adopted in California for peaches failed at times to prevent fruit and leaf infection in the apricot effectively, the Experiment Station[11] made studies for several years in the Sacramento Valley. The autumn application, as recommended for peaches, was found necessary in controlling bud infection during the winter, but should be supplemented by applications when the petals started to show and after the husks or calyxes fell. Experiments in Australia[14, 15, 16] resulted in a similar program for apricots. Only two sprays, however, were recommended: in the autumn after leaf fall and at the "pink-bud" stage in the spring.

Except for brief reports from Switzerland[13, 32] dealing with the control of the disease on cherries, little further experimental information is available. Recommendations, however, appear from time to time in spray calendars and popular bulletins.[4, 12]

Almond growers generally agree that the spray program recommended for peaches is not satisfactory for their crop and that the multiple-spray program for apricot is too expensive. The primary object of the spray experiments in almond has been to determine whether the disease could be controlled by an economical number of sprays.

In 1935, blight caused serious loss of fruiting wood and of foliage in peaches throughout the Sacramento and San Joaquin valleys. Two questions were raised by this outbreak: (1) How much latitude is allowable in the application of the autumn spray? The procedure generally followed is to apply the spray sometime between November 15 and December 15, the time depending upon leaf fall and other factors. Surveys in Sutter County in the spring of 1935, however, indicated that sprays

applied after the first week in December were too late for effective control in that year. (2) Is the autumn spray effective in preventing leaf infection? In other states[4, 12] sprays have been employed in the spring to prevent fruit and leaf infection; but this practice has not been common with peach growers in California, the autumn spray being considered sufficient.

Several recently developed fungicides were included in these tests. Since most of these materials were tested for only one year, the results are merely indicative of their efficiency.

Experimental Plots.—Experimental plots of almonds were located during 1934 and 1935 in Sutter County and during 1936 in Sutter and Sacramento counties. The varieties in the former county were Ne Plus Ultra and Drake; that in the latter county was Nonpareil.

Experimental plots of peaches were located in Sacramento and Merced counties. The Sacramento County orchard was planted with the Paloro variety; the Merced County orchard with Peak and Gaume.

Spray Materials Used in the Control Experiments.—Bordeaux mixture was made with two types of materials, as follows: (1) homemade bordeaux prepared with a high-calcium, finely ground quicklime (unslaked) and with commercial crystals of copper sulfate (bluestone); or (2) "two-package bordeaux" made with finely ground high-calcium, hydrated lime (slaked), and finely ground copper sulfate. The type of materials and the concentration are indicated in their appropriate connections. The homemade bordeaux mixture was prepared as follows: About two-thirds the required amount of water was run into the spray tank, and to this was added the previously prepared copper sulfate solution. The lime was slaked and was diluted with water to a thin paste. With the agitator running, the milk of lime was poured on the screen of the spray tank and washed into the tank with water. The spray was applied immediately after preparation. Bordeaux mixture was prepared from the two-package material as follows: With the agitator running, the copper sulfate was slowly sifted into the spray tank, which contained about two-thirds the required amount of water. After the copper sulfate had dissolved, the lime was then added by washing it through the screen with the water required to bring the spray up to volume.

Lime-sulfur was a liquid material with a specific gravity of not less than 32° Baumé.

Basicop was the so-called "basic copper sulfate," containing 52 per cent metallic copper. In preparing the spray, this material was first mixed with water to make a thin paste; then, with the agitator running, the paste was poured into the spray tank containing the correct amount

of water. To each 100 gallons of spray was then added ½ pint of a soap spreader (Spra-On) recommended by the manufacturers for use with Basicop.

Coposil was copper ammonium silicate containing 22 per cent metallic copper and 3 per cent metallic zinc. The material, stirred in water to a thin paste, was poured into the spray tank as with Basicop. To each 100 gallons of spray was added 1 gallon of a dormant-type oil emulsion (Kleenup A).

Ortho Kleenup A oil emulsion was a dormant-type oil emulsion containing 83 per cent by volume of petroleum oil, which had an unsulfonated residue of 70 per cent.

Funjona was a summer-type oil emulsion containing copper resinate (copper content 0.1 per cent). This material was used at the rate of 1 gallon to 50 gallons of water.

Coprol was a dormant-type oil emulsion containing 0.23 per cent copper in the form of copper naphthanate. As used at the Merced County peach orchard it was emulsified with water and was applied at the rate of 12 gallons of oil per acre.

Avon was a dormant-type oil emulsion containing 2 per cent metallic copper in the form of copper resinate and cuprous oxide. It was emulsified with water and applied at the rate of 10 gallons of oil per acre.

In the Vapodust treatment the material used was an unemulsified dormant petroleum oil in which had been suspended 1 pound per gallon of Coposil. This preparation was applied with the Vapodust machine at the rate of 10 gallons of oil per acre.

Results of Spraying Almonds.—In 1934, the first year of almond experiments, applications were made in the spring: (1) on February 10, when the blossom sepals were projecting from between bud scales; (2) on February 20, when the blossoms were entirely exposed but before the petals had opened; and (3) on February 27, when about 10 to 15 per cent of the blossoms had opened. No autumn sprays were applied.

According to the results in table 1, blossom infection on unsprayed trees was moderately severe, 19 per cent of the blossoms being infected in the Drake variety and 45 per cent in Ne Plus Ultra. Leaf infection, though abundant enough for test purposes, caused no serious defoliation. Bordeaux mixture applied when the blossoms were emerging from the buds reduced both leaf and blossom infection. About the same control was obtained by bordeaux application after the blossoms had entirely emerged. When trees that had received a February 20 application were sprayed again on February 27, no further reduction of blossom infection was noticeable. The reason was that infection had occurred and the lesions had appeared by February 26, one day before this application

was made. The February 27 application did, however, increase the control of leaf infection. These results apparently agree with those obtained for apricot in California[11] and in Australia,[16] since a spray application was recommended at the "pink-bud" stages in both instances.

TABLE 1

RESULTS OF SPRAYING FOR THE CONTROL OF THE SHOT-HOLE DISEASE OF DRAKE AND NE PLUS ULTRA ALMONDS IN THE SUTTER COUNTY ORCHARD, 1934

Variety and treatment*		Per cent of blossoms infected on March 10	Per cent of leaves infected on April 6
Drake variety	Unsprayed	19	31
	Bordeaux mixture, Feb. 10	6	17
	Bordeaux mixture, Feb. 20	5	18
	Bordeaux mixture, Feb. 20 and Feb. 27	5	7
	Funjona, Feb. 20 and Feb. 27	13	27
Ne Plus Ultra variety	Unsprayed	45	41
	Bordeaux mixture, Feb. 10	11	32

* Information as to the preparation and concentrations of these spray materials appears on pages 20-21. Bordeaux mixture, 5-5-50, was prepared from finely ground copper sulfate and hydrated lime.

Condition of trees at time of spray application: February 10, tips of blossoms projecting between bud scales; February 20, blossoms entirely exposed, but no petals open; February 27, 10 to 15 per cent of blossoms open.

TABLE 2

RESULTS OF SPRAYING FOR THE CONTROL OF THE SHOT-HOLE DISEASE OF NE PLUS ULTRA ALMONDS IN THE SUTTER COUNTY ORCHARD, 1935

Treatment*	Per cent of blossoms infected on March 8	Leaf infection† on March 13		Defoliation,† per cent of leaves off the trees on May 2	Yield in pounds of unhulled nuts per tree
		Per cent infected	Number of lesions per 100 leaves		
Unsprayed	5	43	70	53	10
Bordeaux mixture, Jan. 26	1	5	5	16	30
Bordeaux mixture, Jan. 26 and Feb. 13	1	2	3	6	31
Bordeaux mixture, Feb. 13	2	23	25	29	12
Bordeaux mixture, Feb. 13 and Feb. 23	2	25	26	11	24
Basicop, Feb. 13	5	37	..	44	10
Basicop, Feb. 13 and Feb. 23	7	39	96	33	20

* Information as to the preparation and concentrations of spray materials appears on pages 20-21. Bordeaux mixture 6-6-50 was prepared with finely ground copper sulfate and hydrated lime. Condition of trees at time of spray applications: January 26, blossom buds swelling, but no blossom parts exposed; February 13, blossoms emerging from between bud scales, but no petals open; February 23, 10 to 15 per cent of blossoms open; an average of three leaves per spur unfolded.

† The percentage of defoliation is somewhat higher in certain cases than the percentage of leaves infected, because the observations on defoliation were made somewhat later than the observations on leaf infection.

The Funjona, applied when buds were emerging and again after they were entirely exposed, gave distinctly less control of both blossom and leaf infection than did the parallel bordeaux program.

The results of 1934, though encouraging, indicated a weakness in the programs followed. In the first place, the earliest spray (February 10) did not prevent infection in blossom buds that were just swelling. In the second place, control of leaf infection was not entirely satisfactory except where two sprays were applied. As mentioned earlier, these experiments aimed at the development of an economical spray program. More than one spray would probably be considered too costly for almonds.

The experiments of 1935 therefore included a much earlier spray than those of 1934. This spray was applied on January 26, when the blossom buds were beginning to swell but before the bud scales had separated enough to expose blossom parts. Sprays were also applied when the blossoms were emerging from between bud scales and again when 10 to 15 per cent of the blossoms were opened.

Although blossom infection (table 2) in unsprayed trees was comparatively sparse during 1935, leaf infection was abundant. By March 13 an average of 43 per cent of the leaves were infected, and by May 2 the disease had increased so that the trees were 53 per cent defoliated. The disease also caused much cracking and malformation of fruit. The greatest loss of crop, however, resulted from defoliation, undiseased as well as diseased fruit dropping in great numbers when trees lost their leaves. Although the data in the last column of table 2 indicate that certain spray applications increased yields materially, they must be interpreted conservatively, because certain factors, including a rather severe and uneven infestation of red spider, may have influenced yields to a considerable extent.

The application of bordeaux mixture to the trees just as the buds were beginning to swell (January 26) materially reduced leaf infection and the subsequent defoliation, increasing the yield of nuts 200 per cent. A second application of bordeaux when the blossoms were emerging from the bud (February 13) further reduced infection in trees sprayed on January 26. The February 13 application alone, however, did not satisfactorily control the disease on leaves; nor did it increase the yield of nuts. When trees sprayed on February 13 were again sprayed on February 23, no reduction of leaf infection above that occasioned by the February 13 spray was noted in observations made March 13. The February 23 spray apparently did prevent, however, considerable leaf infection after March 13, as indicated by the data on defoliation (column 5, table 2), and increased the yield of nuts as well. The reason why the February 23 spray did not promote the control of early leaf infection beyond that obtained by the February 13 application was, undoubtedly, that the first infection occurred before this spray was applied. This view appears correct because three leaves per spur had unfolded by February

23 and because the disease appeared only a few days after this date. Since the first three leaves were exposed, the February 23 application did, however, protect them from infection after this date and, in consequence, materially reduced defoliation.

According to the data on crop yields (table 2), the February 23 spray appeared also to prevent a reduction of the crop. The amount of fruit harvested paralleled the amount of defoliation more closely than it did

TABLE 3

RESULTS OF SPRAYING FOR CONTROL OF THE SHOT-HOLE DISEASE OF NONPAREIL AND NE PLUS ULTRA ALMONDS IN THE SACRAMENTO COUNTY AND SUTTER COUNTY ORCHARDS, 1935–36

Variety and treatment*	Per cent of blossom buds and blossoms infected on Feb. 26-27	Leaf infection on March 6-8		Twig infection on March 6-8	
		Per cent infected	Number of lesions per 100 leaves	Per cent infected	Number of lesions per 100 twigs
Nonpareil variety					
Unsprayed	18	45	80	54	165
Bordeaux mixture, Oct. 18	17	23	46	43	122
Bordeaux mixture, Nov. 1	17	28	50	20	65
Bordeaux mixture, Nov. 15	13	13	27	10	35
Bordeaux mixture, Jan. 29	4	4	8	46	108
Lime-sulfur, Oct. 18	17	32	31	47	106
Lime-sulfur, Nov. 1	18	40	72	24	72
Lime-sulfur, Nov. 15	19	32	58	9	29
Ne Plus Ultra variety					
Unsprayed	84	66	155	49	112
Bordeaux mixture, Nov. 1	69	50	78	33	68
Bordeaux mixture, Nov. 19	55	29	44	39	79
Bordeaux mixture, Jan. 18	17	30	48	42	71

* Information as to the preparation and concentrations of the spray materials appears on pages 20-21. Bordeaux mixture, 5-5-50, was prepared from commercial copper sulfate crystals and quicklime.

the initial amount of leaf infection, as is shown by the results for the plot receiving bordeaux on February 13 and 23. These data substantiate the observation, noted above, that greater loss of crop was occasioned by defoliation than by direct fruit attack.

Basicop was decidedly less efficient than bordeaux in preventing blossom or leaf infection. The trees receiving both the February 13 and the February 23 applications of this material yielded considerably more fruit than did those sprayed only on February 13; but they did not equal the bordeaux-sprayed trees in this regard.

In the experiments of 1935–36 a January application was again tested. The application at the time the blossoms were emerging from the buds (the February sprays in 1935), being of value only as supplementary sprays, were dropped from the trials. Tests of early and late autumn applications were added to the experiment. These tests in one orchard included spraying with bordeaux and lime-sulfur on October 18, November 1, and November 15; and in a second orchard, spraying with bordeaux on November 1 and November 19. The results appear in table 3.

Blossom infection was moderately severe in unsprayed trees of Nonpareil but very severe in Ne Plus Ultra. The cause was probably, in part at least, the differences in the blooming dates between the two varieties, in relation to a prolonged rainy period extending from February 10 to February 25. The blossoms of certain Ne Plus Ultra trees located in the same orchard with the Nonpareil began to emerge from the buds about February 12 and were therefore exposed to infection during the major part of the rain. Blossoms of Nonpareil, on the other hand, did not emerge from the buds until about February 20 and, in consequence, were not exposed to infection so long as those of Ne Plus Ultra. There may, of course, be difference in blossom susceptibility between the two varieties—a question difficult to answer without extensive inoculation trials.

No attempt was made to determine the effect of blossom infection on set of fruit because unfavorable weather conditions prevented most of the blossoms from setting.

The two varieties under test differed in amount of leaf infection for apparently the same reasons that they differed in blossom infection: the leaves of Ne Plus Ultra appeared earlier than did those of Nonpareil and were therefore exposed to more infection. Because of climatic conditions in 1936, the first leaves unfolded much earlier in relation to blossom development than in most years. Tips of the first two leaves were projecting from the bud at about the time the first blossoms opened, whereas in 1934, for example, the trees were in full bloom before the first leaf appeared.

The results obtained (table 3) by spraying trees at different times during the autumn and winter confirm those of the preceding season (table 2) in that the January application reduced blossom and leaf infection considerably, even though made while the trees were still dormant. Results with Ne Plus Ultra were less satisfactory. According to the data, however, although the percentage of leaves infected was reduced a little over one-half by the January 18 application, the number of lesions per leaf was reduced more than two-thirds. Control of blossom infection by the January 18 application was satisfactory, infection in Ne Plus Ultra being about one-fifth of that in unsprayed trees.

Fall applications of bordeaux mixture and lime-sulfur were, on the whole, unsatisfactory. Trees sprayed with bordeaux in mid-November, however, were considerably freer of leaf infection than those sprayed earlier. In other words, as shown by table 3, the later the bordeaux was applied (up to and including most of January), the better the control of leaf infection. To understand why the disease was prevented on leaves by a spray applied while the tree was still dormant, we must recall the

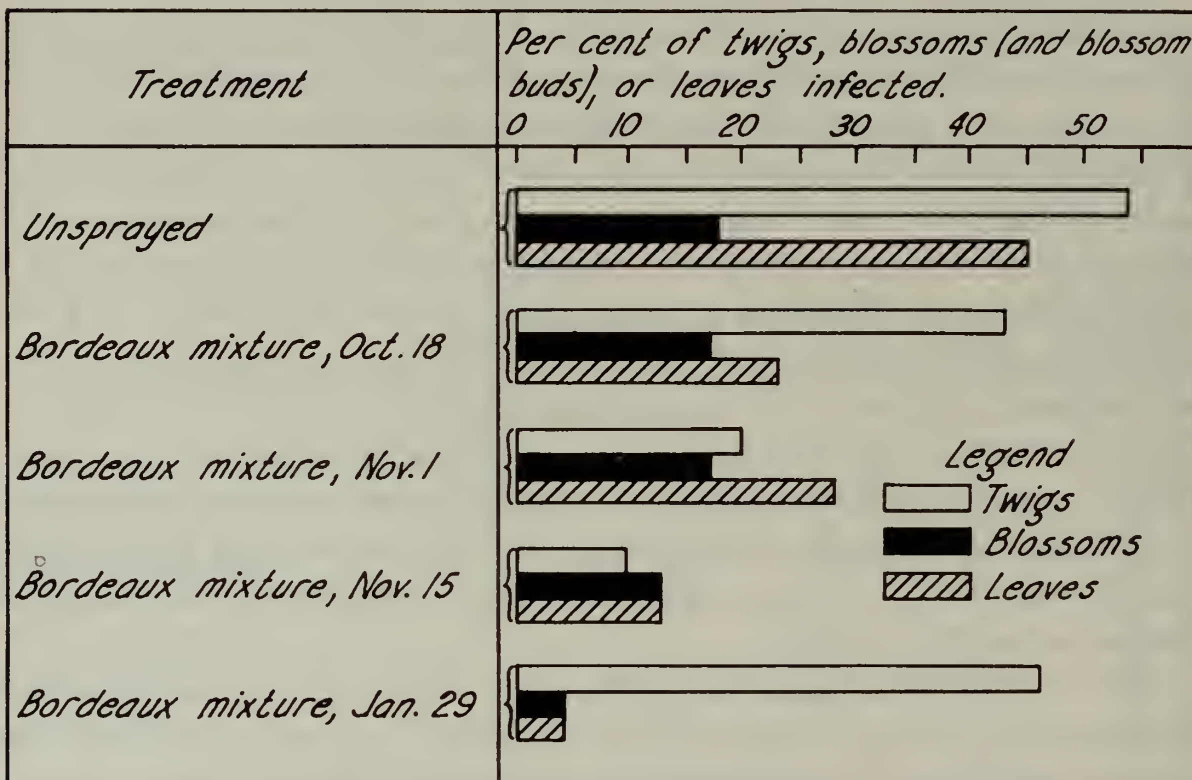

Fig. 9.—Relation of twig infection and blossom-bud and blossom infection to leaf infection in Nonpareil almonds, 1935–36.

nature of the fungus and the development of the disease, as discussed earlier: the fungus spores are adapted to dissemination by rain, but are probably not spread about by wind when the trees are dry. Although carried downward in great numbers during rains, they are probably not so freely spread in a lateral direction. The way in which the disease first attacks blossom buds when they are opening, and in which the diseased blossom parts act as sources whence spores are spread to leaves and fruit, was mentioned in the disease discussion. Evidently, therefore, any treatment that reduces infection of blossom buds and blossoms will also tend to reduce leaf infection. According to the data in figure 9, treatments that controlled blossom infection also controlled leaf infection. In peaches, as will be shown later, twig lesions are important sources whence the spores spread to the leaves. That this was apparently not the case with

the almond can be seen from the data in figure 9. On Nonpareil almonds, for example, the November 15 bordeaux application, though giving much better control of twig infection than the January 29 application, did not control leaf infection nearly so well. Hence, preventing the disease from

TABLE 4

RESULTS OF SPRAYING FOR THE CONTROL OF THE SHOT-HOLE DISEASE OF PALORO PEACHES IN THE SACRAMENTO COUNTY ORCHARD, 1935–36

Treatment*	Twig infection on Feb. 26		Leaf infection on April 17	
	Per cent infected	Number of lesions per 100 twigs	Per cent infected	Number of lesions per 100 leaves
Unsprayed, plot 1	74	218	89	316
Unsprayed, plot 2	83	345	84	390
Bordeaux mixture, Oct. 18	18	26	45	123
Bordeaux mixture, Nov. 6	18	21	41	108
Bordeaux mixture, Nov. 18	13	14	40	100
Bordeaux mixture, Jan. 6	72	113	71	327
Bordeaux mixture plus oil, Oct. 18	13	19	44	87
Bordeaux mixture plus oil, Nov. 6	12	14	39	93
Bordeaux mixture plus oil, Nov. 18	9	9	40	69
Bordeaux mixture (hydrated lime), Nov. 18	9	11	37	80
Basicop, Nov. 6	55	128	61	188
Basicop, Nov. 18	34	44	71	199
Coposil, Nov. 6	27	53	70	185
Coposil, Nov. 18	28	43	64	214
Vapodust, Dec. 12	14	40	55	170
Lime-sulfur, Nov. 6	80	220	72	194
Lime-sulfur, Nov. 18	52	130	66	229
Lime-sulfur, Jan. 6	76	180	70	322

* Information as to the preparation and concentration of these spray materials appears on pages 20-21. Bordeaux mixture in all cases was 5-5-50 and except where indicated was made with quicklime. Bordeaux mixture plus oil contained 4 gallons per 100 gallons of a dormant oil emulsion (Kleenup A).

attacking blossoms would appear to be more important in controlling leaf infection than in the prevention of twig infection.

The January 29 application gave better control on blossom buds and blossoms of Nonpareil almonds than did earlier applications, possibly because much of the spray material was still present on the buds when infection occurred as they began to open. In autumn applications the spray material, having been largely weathered away by spring, did not adequately prevent infection at the time the buds began to open. A more detailed discussion of this point appears later in this section.

Results of Spraying Peaches in Sacramento County.—The spray tests in peaches were designed to obtain information on the following questions: (1) At what time during autumn or winter will a spray give maximum control of twig infection? (2) Will sprays applied against twig infection be instrumental against leaf infection? (3) Do lime-sulfur and

bordeaux give equal control? (4) Is bordeaux prepared with hydrated lime as effective in preventing the disease as bordeaux made with quicklime? (5) Does the addition of a dormant type of oil emulsion to bordeaux affect its value? (6) Can satisfactory control be obtained with Basicop, Coposil, and a Coposil-containing dormant oil applied as a very fine mist (Vapodust)?

At the Sacramento County orchard the sprays were applied with relation to the condition of the trees as follows: October 18, before leaves were off the trees; November 6, after practically all leaves were off; November 18, trees dormant; and January 6, trees dormant. The relation of the spray application to rainfall and to the development of twig infection is shown in figure 8. No results could be secured relative to the amount of fruit infection, since the crop was destroyed by frost.

Twig infection was abundant in the unsprayed trees at the Sacramento County orchard (table 4). Leaf infection, though sufficiently abundant for test purposes, did not cause so much defoliation as in 1935. By April 17, about 15 per cent of the leaves had dropped from unsprayed trees. Defoliation in sprayed plots ranged from 10 per cent in trees receiving lime-sulfur or bordeaux mixture on January 6 to a negligible amount in trees receiving bordeaux on November 18. Between 5 and 10 per cent of the foliage fell from trees sprayed November 6 with lime-sulfur, Basicop, or Coposil.

Bordeaux mixture (without oil) applied on any of the three dates—October 18, November 6, or November 18—greatly reduced twig infection; the later the application, up to the last-named date, the more effective the control, as was the case also with the other fungicides tested at this orchard. To understand these results fully, further data must be presented; but, since these data concern the experiments conducted in Merced County as well, they are discussed later in the paper.

The addition to bordeaux mixture of a dormant-type oil emulsion strong enough for scalecide purposes apparently increased its efficiency somewhat, inasmuch as twig infection was reduced to a greater degree by each of the three different applications of bordeaux with oil than by the parallel application of bordeaux without oil.

Bordeaux mixture prepared with hydrated lime gave as good control as did bordeaux mixture prepared with quicklime.

Basicop, Coposil, and Vapodust were not satisfactory in preventing either twig or leaf infection.

In the present tests lime-sulfur proved a poor substitute for bordeaux; not only did it fail to effectively control twig infection, but the applications made on November 6 considerably injured the current-year's twigs.

The question of whether sprays applied to prevent twig infection

would also prevent leaf infection was answered in part by these tests. The fact that leaf infection was less severe than it might have been should be kept in mind. Under more favorable conditions in the spring the disease would have probably done more damage even in trees where the twig disease was well controlled. Nevertheless (fig. 10), the amount of

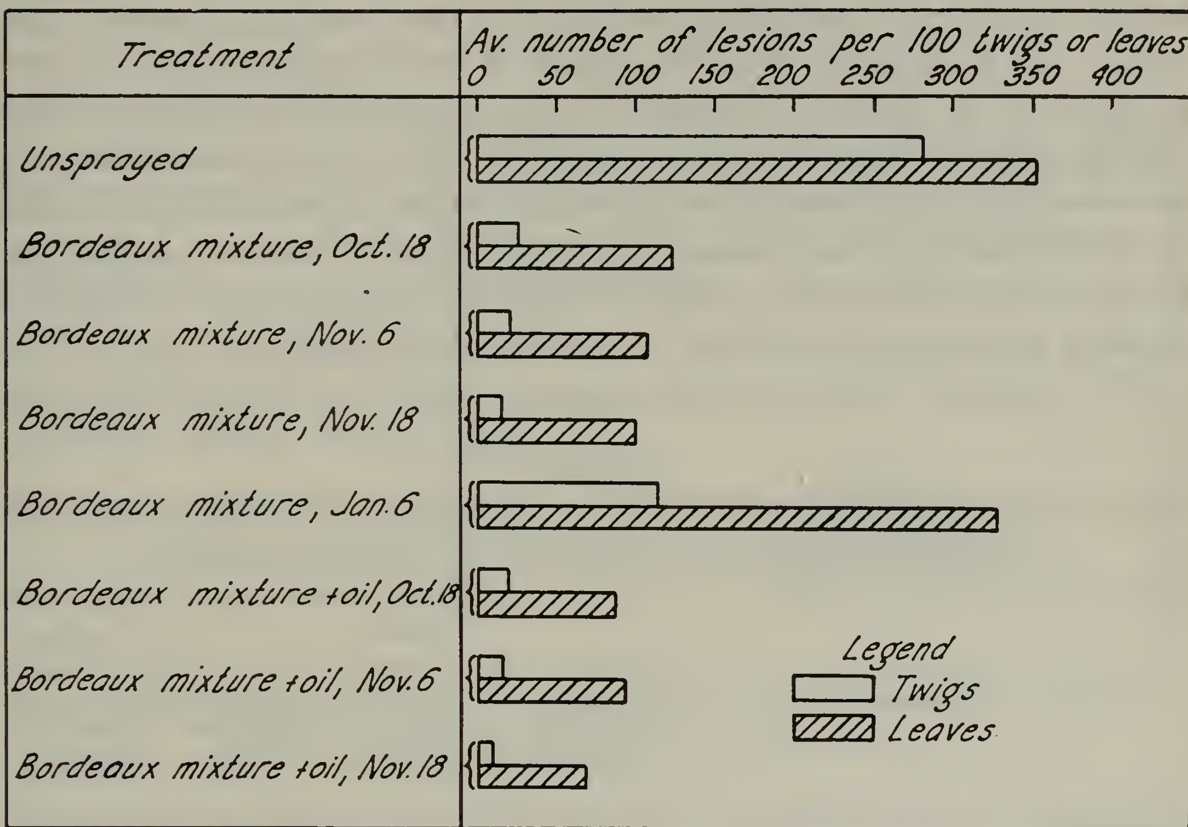

Fig. 10.—Relation of the control of twig infection to the control of leaf infection in peaches at the Sacramento County orchard, 1935–36.

the disease on leaves followed very closely the amount on twigs. In other words, the sprays most effective against twig infection were also most effective against leaf infection.

The results assume greater significance when we consider that the tests were conducted in trees badly diseased during 1934–35; and, as mentioned in the foregoing section, when the leaves appeared on these trees in the spring of 1936, viable conidia were abundant on twigs that had been infected during the winter of 1934–35. Evidently, therefore, even though twig infection was controlled perfectly during the winter of 1935–36, leaf infection in the spring of 1936 might have resulted from the conidia that came from old lesions developed during the winter of 1934–35.

Results of Spraying Peaches in Merced County.—At the Merced County orchards the spray tests were designed to obtain information on the following questions: (1) At what time during autumn or winter will

a spray give maximum control of twig infection? (2) Will a spray applied for twig-infection control aid in reducing leaf infection (3) Can the disease be controlled with certain copper-containing dormant spray oils (Coprol and Avon)?

In relation to the condition of the trees, the spray applications were timed as follows: November 1, a few leaves remained on the tree; November 15, December 3, and December 16, the trees were in a dormant condition. The relation of rainfall to dates of spray applications is shown in figure 8. At Merced, evidently, there were fewer and lighter rains during early autumn than at Sacramento. The winter rains, however, were roughly of the same intensity and duration at both places. Though the development of the disease in Merced County was not observed at frequent intervals, major waves of twig and leaf infection were noted at about the same time as those in Sacramento County.

The results of the spray tests appear in table 5. Twig infection was

TABLE 5

RESULTS OF SPRAYING FOR THE CONTROL OF THE SHOT-HOLE DISEASE OF PEAK AND AND GAUME PEACHES IN THE MERCED COUNTY ORCHARD, 1935–36

Treatment*	Peak			Gaume
	Number of lesions per 100 twigs on March 10	Per cent of leaves infected on April 24	Number of lesions per 100 leaves on April 24	Number of lesions per 100 twigs on March 10
Unsprayed	853	70	300	1,010
Bordeaux, Nov. 1	121	38	64	138
Bordeaux, Nov. 15	87	36	48	150
Bordeaux, Dec. 3	69	28	24	113
Bordeaux, Dec. 16	29	30	27	116
Kleenup A, Nov. 7	324	63	278	409
Coprol, Nov. 7	315	64	210	726
Coprol, Nov. 15	263	59	156	769
Coprol, Dec. 3	92	52	96	635
Coprol, Dec. 16	127	50	116	277
Avon, Nov. 15	112	40	100	603
Avon, Dec. 3	49	41	110	435
Avon, Dec. 16	56	34	72	409

* Information as to the preparation and concentration of spray materials appears on pages 20-21. Bordeaux mixture, 5-5-50, was prepared from finely ground copper sulfate and hydrated lime.

considerably more severe in this orchard than in the Sacramento County orchard. Leaf infection was, however, less severe; and defoliation was therefore of minor importance. Blossom infection was common in the Gaume variety on unsprayed trees and on trees receiving Coprol and Avon.

As in Sacramento County, the twig-infection control secured with bordeaux mixture 5–5–50 varied with the dates of application. Poorest

control was given by the November 1 application, and best control by the December 16 application, except that in the Gaume peach the December 3 and December 16 applications prevented twig infection to about the same degree.

Somewhat the same relation of control to date of application was evidenced by the results obtained with Coprol and Avon. These materials, however, did not prove satisfactory. A dormant-type oil emulsion

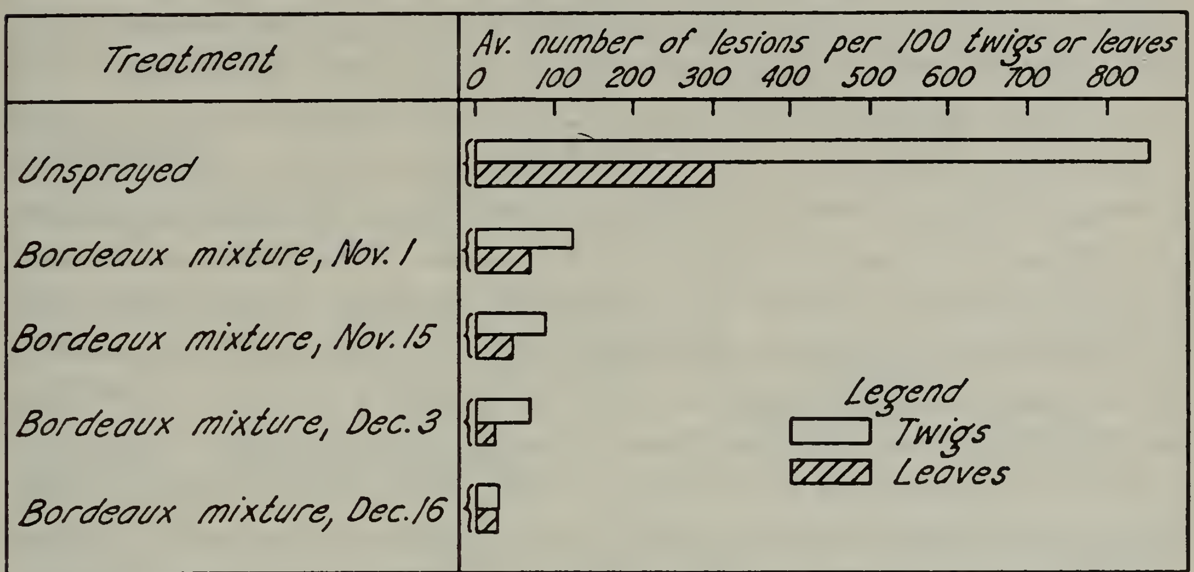

Fig. 11.—Relation of the control of twig infection to the control of leaf infection in peaches at the Merced County orchard, 1935–36.

(Kleenup A) prevented the disease to some extent, but not enough to permit its use alone.

The reasons why early-winter applications gave better control of twig infection than did autumn applications will be discussed later in this section.

The data in figure 11 are arranged to show the relation between the amount of twig infection developing in the trees during the winter of 1935–36 and the amount of leaf infection developing during the spring of 1936. As in the Sacramento County orchard, the disease on leaves was least severe where twig infection was most successfully controlled.

Relation Between the Durability of Spray Coating and the Control of Twig Infection.—Although laboratory tests may prove a spray material to be highly toxic when in contact with spores of a fungus, the material will not adequately control the disease if it does not adhere well to the tree. After being applied the spray coating is subjected to the deteriorating influences of weather conditions, the most important of which is probably rain. With the shot-hole disease in particular, the spray coating must retain its effectiveness over a long period. In 1935–36, for example, abundant twig infection of peach occurred during the series of rains

between December 26 and January 13, and during the long rain between February 10 and February 25 (fig. 8). To prevent twig infection successfully, therefore, the spray should have been applied before December 26; and the spray coating should have remained effective throughout these periods at least, or about two months.

The results secured in most of the tests on both almonds and peaches showed that the early-autumn spray applications controlled twig infection less efficiently than did late-autumn or early-winter applications (figs. 9, 10, and 11). The nearer the date of spray application was to the first major infection period, which began on December 26, the better was control of the disease of the twigs. Thus at the Sacramento County peach orchard the percentage of control obtained with autumn application of bordeaux mixture increased as follows: October 18, 91 per cent; November 6, 93 per cent; and November 18, 95 per cent. The difference between these percentages, though small, appears significant inasmuch as the corresponding applications of bordeaux with oil gave similar increase as follows: October 18, 92 per cent; November 6, 95 per cent; and November 18, 97 per cent. At the Merced County peach orchard, control of twig infection obtained with bordeaux mixture applied at different times during the autumn and early winter was as follows: November 1, 86 per cent; November 16, 90 per cent; December 3, 92 per cent; and December 16, 97 per cent. Table 3, furthermore, shows practically the same situation for the almond experiments of 1935–36. Both bordeaux and lime-sulfur applied in late autumn gave better control of twig infections than they did when applied in early autumn.

According to these data, the effectiveness of the spray bore a close relation to the date of its application. The later the application, up to a certain time in the early winter, the more effective was the spray in preventing twig infection. This relation is clearly shown in the data secured at the Merced County peach orchard (fig. 12). According to observations on Februry 6, after the appearance of the first large wave of twig lesions initiated during the rains between December 26 and January 13, the four separate applications of bordeaux mixture controlled twig infection equally well. By March 10, however, after the appearance of the second large wave of disease, initiated during the rain between February 10 and 25, the four applications of bordeaux were no longer controlling twig infection to the same degree. Instead, the earlier applications were markedly less effective than the later. Between February 6 and March 10 twig infection increased 13-fold in trees sprayed November 1; 12-fold in trees sprayed November 16; 7-fold in trees sprayed December 3; and only 3-fold in trees sprayed December 16. By late winter, in other words, the effectiveness of the earlier applications was reduced to a low level,

probably because they had undergone more weathering than the later applications.

In order to learn something about the weather-resisting qualities of the different copper fungicides, applied to peach trees in the Sacramento orchard, in relation to their control of the disease, a series of copper analyses were made during the winter of 1935–36. On November 18,

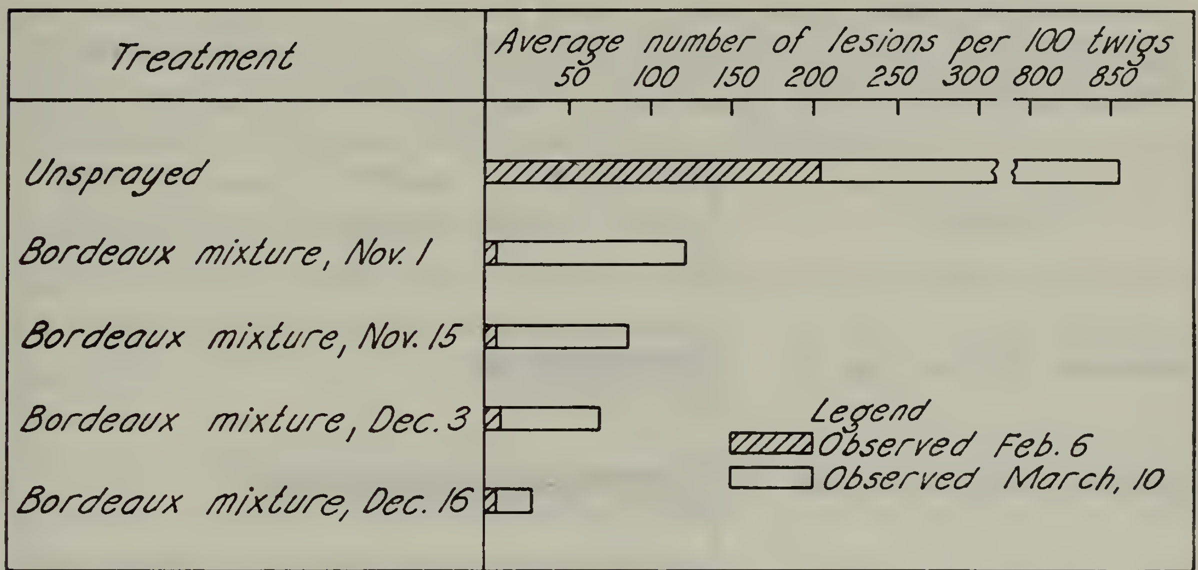

Fig. 12.—Relation of the time of applying sprays to the control of peach-twig infection at the Merced County orchard, 1935–36.

January 6, and January 28 duplicate 150-gram samples of twigs produced during 1936 were taken from trees sprayed on November 18. The amount of metallic copper on the twigs was determined as follows: The twigs were placed in clean glass jars containing 500 cc of water, to which had been added 11 cc per liter of nitric acid (sp. gr. 1.42). The glass tops were fastened in place, and the jars were shaken vigorously until tests showed that all copper had been removed from the surfaces of the twigs. A given amount of this wash water was treated with a few drops of a 2 per cent potassium ferrocyanide solution. The color which developed was matched in a block comparator with that of standards containing known amounts of metallic copper in the form of copper sulfate. Results appear in figure 13.

As indicated by the analyses made on November 18, the various spray materials deposited different amounts of copper on the twigs. Since each fungicide was applied to the tree at practically the same rate, the differences in the amount of copper deposited, except for bordeaux mixture with oil, must have resulted from differences in the copper content of the fungicides. The bordeaux mixture, for example, contained about 1.24 pounds of metallic copper per 50 gallons of spray; the Basicop 1.56

pounds; the Coposil 0.66 pound. The relative amounts of copper deposited by these materials evidently vary according to their copper content.

Bordeaux mixture with oil, on the other hand, contained as much copper as bordeaux mixture without oil and was applied at the same rate; yet it deposited less copper on the twigs. The reason for this difference is not known.

The analyses made on January 6 and January 28 indicated that the copper had been greatly reduced in all cases except that on trees receiving bordeaux with oil. It practically disappeared from twigs sprayed

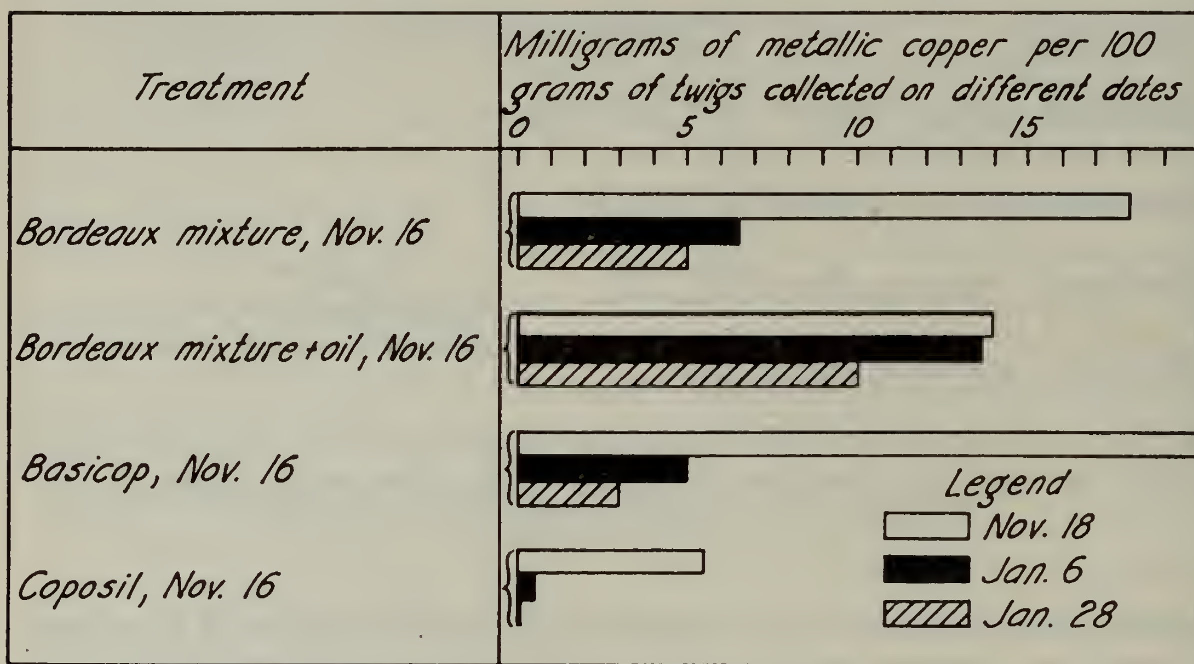

Fig. 13.—The weather-resisting qualities of several fungicides used for spraying peaches at the Sacramento County orchard, 1935–36.

with Coposil, was reduced to a low level on twigs sprayed with Basicop, but remained in somewhat greater quantities on those receiving bordeaux mixture without oil. Although depositing less copper, bordeaux mixture with oil was apparently more durable than either bordeaux without oil or Basicop. Unpublished results of studies in Oregon show, according to certain workers interested in the use of this material against citrus disease and insects in Florida,[34] that oil emulsion increased the durability of bordeaux mixture applied to apple trees for the control of anthracnose [*Neofabraea malicorticis* (Cord.) Jackson].

That the control of peach-twig infection obtained with these fungicides paralleled their weather-resisting abilities is seen by comparing the data in table 4 with those in figure 13. The control obtained with bordeaux mixture plus oil, though not greatly exceeding that obtained with bordeaux mixture alone, was consistently better. Bordeaux without oil, in turn, controlled twig infection much better than did Basicop or Coposil.

SUMMARY AND CONCLUSIONS

This paper describes the symptoms of the peach blight or shot-hole disease occurring on peach, almond, and apricot. Although attacking twigs, dormant buds, leaves, blossoms, and fruit, the disease varies considerably in its severity on different organs of these three stone fruits. The importance of the disease on the various organs in relation to control procedure is described.

The known hosts of the fungus are peach, apricot, nectarine, almond, European plum, cherry-laurel, several species of wild and cultivated cherry, and *Prunus davidiana.* In California the hosts consistently suffering loss are peach, nectarine, almond, and apricot.

The fungus is described briefly, and illustrations of the spores and spore-bearing organs are included.

In California, the fungus is required to survive weather conditions in summer which do not favor its development. It does so on peaches as mycelium in the tissues of diseased twigs and buds. Conidia which are produced within blighted buds are apparently able to survive the hot, dry summers in California and are, in consequence, also instrumental in carrying the fungus from one season to the next. In apricots the hold-over sources of the fungus are the blighted dormant buds, lesions on twigs being rare. In almonds, the fungus survives as mycelium in twig lesions, as mycelium and spores in blighted dormant buds, and to some extent as mycelium and spores in blighted blossoms that remain on the tree from year to year. In the experimental orchards lesions on almond twigs, being sparse on otherwise badly diseased trees, were apparently not so important as blighted buds in carrying the fungus from one season to the next.

Rain is probably the factor most responsible for spreading the fungus about the trees. Spores produced in blighted buds or on lesions along the surfaces of branches are not easily dislodged by currents of dry air. Drops of water, however, falling upon the diseased parts, dislodge numerous spores and carry them downward. Possibly a strong wind may carry these spore-laden drops of water to other trees, though this point has not been proved experimentally.

The length of time between entry of the fungus into the host tissue and appearance of symptoms, according to all available information, is from 5 to 8 days in leaves and from 7 to about 20 days in twigs. Variation in temperature will cause differences in the length of this period.

The influence of climatic conditions on development of the disease was studied to some extent. In two experiments leaf infection did not occur unless the leaves were kept moist for 24 hours or more after inoculation. Under the conditions prevailing during the winter of 1935–36, twig in-

fection was not initiated during the first short rains of autumn, but was initiated in abundance during the long rainy periods of winter. The relation of rainy periods to infection of peach and almond foliage is discussed.

In the three-year control experiments on almond, bordeaux mixture, 5–5–50 and 6–6–50, was the fungicide employed most frequently; but lime-sulfur, Basicop, and Funjona (a copper-containing oil emulsion) were used in a few tests. Although an application when the blossoms were emerging from between the bud scales reduced blossom and leaf infection, and an application after the first two or three leaves were unfolded prevented leaf infection to a considerable extent, they seemed valuable only as supplementary sprays. The application giving most satisfactory control on blossom buds, blossoms, and leaves was one applied in January just as blossom buds were beginning to swell. Autumn applications, though controlling twig infection more effectively than the January spray, were less satisfactory for preventing the disease on blossom buds, blossoms, and leaves.

The main object of the spray tests in peaches was to determine at what time, during autumn or early winter, applications of spray most effectively prevent twig infection. The fungicides used in these tests were bordeaux mixture (prepared both with quicklime and with hydrated lime), bordeaux mixture plus a dormant-type oil emulsion, lime-sulfur, Basicop, Coposil suspended in water, Coposil suspended in a dormant-type oil and applied with a so-called Vapodust machine, and two types of copper-containing oils (Coprol and Avon). In the timing experiments bordeaux mixture was applied at one orchard on October 18, November 5, and November 18; and at another orchard on November 1, November 16, December 3, and December 16. Although applications on any of these dates markedly reduced twig infection, the degree of control was progressively better the later the spray was applied up to the last-named date. At one orchard, on the other hand, bordeaux mixture applied on January 6 failed to control twig infection. These data, in conjunction with those secured in the study of the development of the disease, warrant the conclusion that twig infection could have been successfully prevented by spraying any time up to December 26, the beginning of the rain that initiated the first large wave of disease on twigs. The nearer to this date the spray was applied, the better the control of twig infection.

Lime-sulfur, Basicop, Coposil (suspended in water as well as oil), Coprol, and Avon were less effective than bordeaux mixture.

In one peach orchard the addition to bordeaux mixture of a dormant-type oil emulsion (4 gallons per 100 gallons of spray) resulted in slightly but consistently better control of twig infection.

The relation between the control of twig infection by sprays applied in the dormant season and the consequent reduction of leaf infection was found to be as follows: (1) With almonds, successful prevention of twig infection was not followed by a commensurate reduction of leaf infection. On the contrary, the application of bordeaux mixture, which gave the best control of leaf infection (January application), was too late for twig-infection control. These results are interpreted to mean that in almonds twig lesions, being comparatively sparse in the experimental orchards, were not the major source whence spores spread to leaves. Blighted dormant buds and diseased blossom parts, on the other hand, appear to be the most important sources. Spray applications that prevented the disease from developing on these parts gave the best control of leaf infection. (2) With peaches the sprays that prevented twig infection most effectively also gave the greatest control of leaf infection. This result is interpreted to mean that in peaches, spores that cause leaf-infection come primarily from twig lesions.

A study of the weather-resisting quality of bordeaux mixture, bordeaux mixture plus oil, Basicop, and Coposil revealed that, after several weeks of weathering, the amount of copper remaining on the twigs sprayed with the different materials bore a direct relation to efficiency in controlling twig infection.

The weathering undergone by the bordeaux coating on the trees seems to be the reason why early-autumn applications prevented twig infection less effectively than did later applications. The earlier the application, the greater the amount of copper lost through weathering, and, in consequence, the poorer the control.

RECOMMENDATIONS FOR CONTROL

The time just before the blossom buds begin to swell, generally during late January, seems the most important for spraying almonds. Bordeaux mixture 5–5–50 (or stronger if desired) is the preferable spray material. Apply on a sunny day when the spray will dry quickly. Cover the trees thoroughly with a fine mist, but do not drench them. Since by applying a spray at this time we are attempting, by controlling infection of blossom buds and blossoms, to reduce leaf and fruit infection as well, we cannot expect the single spray to give perfect control under all conditions. The experience with apricots is a case in point. Although the autumn spray is, for apricot, the most important of the several recommended, and although this spray alone is sufficient to control dormant-bud infection and, in consequence, is frequently adequate to reduce fruit and leaf infection, it happens in some years that additional sprays in the spring are necessary to control the disease on fruit and leaves. The

secret of good control in both apricots and peaches is thorough and consistent spraying year after year. As is well known, once the disease is reduced to a low level in apricot trees it is thereafter easier to control. The same situation should be true for almonds.

The results herein reported do not fundamentally alter the earlier spray recommendations for peaches. They do, however, reveal the undesirability of spraying too early and the dangers of delaying the spray until too late in the winter. Among growers the tendency is probably towards delayed rather than early application. Although in 1935–36, good control of peach blight was obtained in one orchard by spraying as late as December 16, this would not be the case if long rains occur earlier in the autumn than they did in 1935. The spray should be applied as soon as the leaves are off. In years when the leaves remain on the tree until late in the autumn, the best policy would be not to delay the spray much later than the end of November. Bordeaux mixture 5–5–50 (or stronger if desired), appears to be the most satisfactory material. Experiments during the winter and spring of 1935–36 indicate that peach leaf curl is successfully controlled by autumn applications of bordeaux mixture. No spray, therefore, need be applied in the spring to control this disease if peach trees are sprayed in the autumn to control the blight.

The spray programs in both almonds and peaches should be supplemented with thorough removal of all diseased parts from the trees.

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